

Analysing global food waste problem: pinpointing the facts and estimating the energy content*

Review Article

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Abstract: Food waste is a global problem. Each year food worth billions of dollars is wasted by the developed economies of the world. When food is wasted, the problem does not end at that point. More than 95% of the food waste ends at landfill sites, where converted into methane, carbon dioxide and other greenhouse gasses by anaerobic digestion. The impact of food waste to climate change is catastrophic. Food waste problem tends to increase in next 25 years due to economic and population growth mainly in Asian countries. In addition, when food wastes buried at landfill sites their energy content is lost. Although food waste is a huge problem, its global size and extent has recently become a hot topic in the academic community. This paper summarises the size of the global food waste problem together with the estimation of the amount of energy lost when food wastes dumped at landfill sites. Calculations in this study also revealed that energy lost at landfill sites equals to 43% of the delivered energy used for the preparation of foods in the US, 37% of the hydroelectric power generation of Japan, and more than 100% of the current annual renewable energy demand of UK industries.

Keywords: Energy content • Environment • Food waste • Greenhouse Gases • Hunger • Waste management

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1. Introduction

Food waste can be defined as any uneaten food or food preparation residues from residences or commercial establishments [1]. In the 21st century, with the presence of supermarkets, and fast food chains, people of the developed world are very different from their ancestors and even from

*This article is dedicated to the memory of Dr. Ruohang Wang, our collaborator and beloved friend, who passed away in July 2010

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the people of developing nations. Not only do we have much better access to food nowadays, but we are also much wealthier. Therefore, we afford to waste more food. With the convenience of excellent food packaging, people today are not always aware of purchasing more than they need and do not think about the food that they are wasting as much as they might have done a hundred years ago. Consequently, in some parts of the world, tonnes and tonnes of food are thrown away into the garbage, while still being consumable.

Meanwhile, in other parts of the world, mainly in third world countries, people are dying of starvation. Global hunger and its impacts are a serious problem of the developed world. A recent report prepared by the United Nations World Food Program pinpointed that 870 million people, which is more than the populations of USA, Canada, and the European Union in total; do not have enough to eat [1]. The vast majority of hungry people, 98%, live in developing countries, where almost 15% of the population is malnourished [2].

On the opposite sides of the equation, food waste and hunger are two serious problems. Ironically, the amount of global food waste is more than enough to feed all the hungry people on the world. Therefore, when tackling with the food waste problem, we should keep in our minds that this is not just an environmental and economical problem but it is also an ethical and moral problem, which should be handled very seriously.

2. Global food waste problem

Globally the amount of food wasted is expressed in terms of billions of dollars [3, 4]. United States, United Kingdom, and Japan are the three advanced economies of the World, which are also on the top of the food waste list. Food supply in the United States is the most varied and abundant in the world. With thousands of different food products available to them, Americans can and do spend more on food than the citizens of any other country. Despite this, their food bills still represent a relatively smaller share of their disposable income. In 1995, 96 billion pounds or 44 million tonnes of food was wasted in the United States. This amount is equal to 27% of the edible food available for human consumption [5].

According to a more recent study, it was estimated that in the United States each year at least 35 million tonnes or 77 billion pounds of edible food, worth nearly \$30 billion, is thrown away from restaurants, convenience stores, and supermarkets alone [6]. Another related study showed that 26% of the food in stock in convenience stores ends in the garbage [7]. Jones also stated that, American households

allow 14% of the food they purchase to end up in their garbage, which costs a family of four nearly \$600 per year and contributes \$43 billion to the American economy, and this waste makes 12–14% of all municipal solid waste disposed in the landfills [8]. The food waste problem in total accounts for around \$75 billion of the American economy annually. According to the Environmental Protection Agency, on top of this huge loss, Americans pay \$1 billion to dispose their food wastes [9].

Although food waste is extremely high in the United States, most Americans are unaware of the many ways in which they contribute to this problem. The food waste problem is not unique to the Americans, on the other side of the Atlantic; in the United Kingdom, Britons also have a significant food waste problem.

According to the report prepared by the Waste & Resources Action Programme (WRAP) of the UK government, it is estimated that one third of the food sold in the United Kingdom ends as waste and half of this is still edible [10]. According to WRAP, annually 8.3 million tonnes of food waste is produced by British households in 2007 [11]. It was estimated that 30% of British households are found to be “high food wasters”, 27% are “medium food wasters”, and 43% are “low food wasters” [12]. The new figures from WRAP showed that there was an estimated 7.2 million tonnes of household food waste in the UK in 2010, 13% reduction from the 8.3 million tonnes thrown away in 2007. However, due to increasing cost of food, which has risen by 20% since 2007, households in the UK are still wasting a staggering £12 billion worth of food [13].

Considering industry related food waste, the food-manufacturing sector in the United Kingdom has an annual turnover of £68 billion and employs over half a million people in about 7,500 businesses and this giant sector produces an estimated waste of 2.7 million tonnes per annum [14, 15].

Although food waste produced in the UK is massive, many of the people do not appreciate the quantity of food they waste. More than 90% of British people claimed that they only waste small amounts of food. They used the words: “some”, “a small amount”, “hardly any”, or “none”, when describing the amount of waste they produced [13]. However, if this is true the remaining 10% percent of the British people should have produced 7.2 million tonnes of food waste annually, which is hard to believe.

Parry identified the annual amount of avoidable food waste that is produced in the United Kingdom is 2.5 million tonnes and has market value, £6.2 billion [16]. Meat and fish products, fresh fruit & vegetables, bread & bakery products are the top three major food wastes in the United Kingdom.

Similar to the US and UK, food waste is a big problem in Japan. Approximately 19 million tonnes of food is wasted in Japan annually [17]. This is equal to 40% of the annual food production [9]. Ironically, self-sufficiency of food in Japan is only 40% [18]. Therefore, Japanese people are throwing away the equivalent amount food as their country is producing.

Other developed economies of Asia also produce a lot of food waste. Hong Kong's booming economy and the metropolitan living style make this city the 'gourmet capital' of Asia, however, the country also has the most imminent food waste management issue among the developed countries in South East Asia with food waste produced per capita as high as 0.45 kg d^{-1} in 2012 [19]. In Taiwan, approximately 16.5 million tonnes of food waste is produced annually [20]. In the Republic of Korea, more than 22% of the municipal solid waste is reported to be food waste and the generation rate of food waste was 0.24 kg d^{-1} in 2004 [21]. This is equivalent to 4.3 million tonnes of food waste annually. Annual production of food waste in Singapore was 570,000 tonnes in 2008 [22]. This means the food waste generation 0.32 kg d^{-1} in 2008. In the 21st century, Asian economies including China and India will keep on growing. Thus, the amount of food waste production will tend to increase in this region. Based on the aforementioned literature review, the amount of global food waste is summarised in Table 1.

Table 1. Amount of Food Waste from Different Countries in 2010

Country	Annual Food Waste (Million Tonnes)
United States	79
Japan	19
Taiwan	16.5
United Kingdom	11
Korea	4.3
Singapore	0.6

3. Major waste food items and food waste management options

Thousands of different food items are wasted globally and it is very hard to quantify each of them. However, from the literature review, it was found that meat, fruit & vegetables, bread & bakery products are the top three major food wastes produced in the developed countries [23, 24]. Food waste is the biggest portion of municipal solid waste (MSW) and causes severe environmental problems such as greenhouse gas emissions due to anaerobic digestion and

leachate production at the landfill site. Management of food wastes follows the general pattern of waste management. This comprises planning, collection, recycling, processing, and disposal of waste materials, and trying to decrease their environmental impacts. For many years, this waste hierarchy has been used in many countries as the basic principle to prioritize different waste management options according to their environmental desirability.

Common interpretation of the waste hierarchy, listed from the most desired to least, is: Prevention of the waste, reuse before wasting, recycling of waste, composting of waste, incineration with energy recovery of waste, land-filling of waste with energy recovery, incineration of waste without energy recovery, landfilling of waste without energy recovery [25].

A modified version of the waste hierarchy has been used in the developed countries when tackling food waste problems [26]. The extent of modification in the waste hierarchy depends on topography, population density, transportation, infrastructure, socioeconomic and environmental regulations of the country [27]. The following list shows these practices in order from the smallest share to the biggest in terms of application: Prevention of food waste, recovering food to feed hungry people; providing food for livestock: pigs, poultry, etc.; composting, and using the compost to improve soil fertility; landfilling or incineration, which is the current general practice, carried out for more than 95% of the food waste.

In theory, the best solution is to stop wasting food. However, this is not as easy as it seems. It is believed that the following quoted text explains the situation best: "Waste prevention at the top of the waste hierarchy is really a catchphrase without much content, the use-and-throw society is a reality with its huge turnover, creating the ever-increasing mountains of waste" [25]. The amount of food waste produced in the developed economies of the world validates this argument.

The second option in the conventional food waste hierarchy is to recover food to feed hungry people. This is a very important issue in terms of ethics, and sanitary conditions. Excess food can be given to the people who need it if, and only if, it is collected properly and hygienically. Moreover, the food must be edible and it must not be spoiled or contaminated. Many government organisations and charities are working with supermarkets and local authorities to collect and distribute to the poor excess or waste food that is edible. However, the main problem with the large fraction of excess or waste food is that it is not always edible and can deteriorate very easily. This makes collection, processing, and transportation for human consumption very difficult.

Excess or waste food has been given to animals for centuries. In many parts of the world, livestock farmers use waste food to feed their animals. Mostly pigs and poultry are the recipients of these food wastes. Swill feeding is a generic term used for waste foods mixed together into pig feed. In the United Kingdom, on 24/05/2001 swill feeding of waste food containing meat was banned as an emergency measure during the Foot and Mouth Disease (FMD) [28]. The aim of the legislation, Statutory Instrument 2001 No. 1704, was to reduce the risk of spreading the foot and mouth disease. However, two years after this legislation a new regulation was put in order around Europe. The Animal By-Products Regulation, EC No: 1774/2002, which prohibits catering waste from being fed to farmed animals. This regulation was applied in all European Union member states immediately from 1st May 2003. Catering waste means all waste food including used cooking oils. This definition also includes catering waste from vegetarian restaurants and kitchens. Based on the new legislations only certain types of waste food can now be given to livestock. Moreover, waste food must be treated properly before being given to animals. However, treating waste food requires time and money, which may not be economically viable for the livestock farmers. Therefore, most of the food waste given to livestock before 2003 would also end up at landfill sites in most of the European countries.

Composting is a biological process for converting solid or semisolid organic materials to a stable, soil like product called compost [29]. Food waste like all other biodegradable wastes can be used for composting as long as the process conditions are maintained. For ideal composting conditions, the waste must have a certain carbon to nitrogen ratio (C:N), which permits microbial activity. This ratio should be between 25:1 and 35:1 [30]. Moisture content between 50% and 65% on wet basis, adequate oxygen supply, small particle sizes, and enough void space are the other parameters that need to be fulfilled [31].

If composting is carried out properly, food wastes can be converted into an environmentally friendly product. In addition, the volume and mass of the waste can reduce up to 40 percent. However, if the process is not carried out properly, offensive odours can be produced. Composting can be carried out at domestic and industrial scales. In western countries, home composting is promoted by local authorities, because waste collection and processing costs are eliminated.

Composting produces only compost but no other value added products. However, other bioprocesses could be developed in order to utilise food wastes, which are essentially similar to composting but which could produce valuable products. The characterization of food waste and

the available bulking agent before composting is of primary importance [32]. However, the composition of the food waste can vary from one location to the next and with time. Therefore, compost recipes need regular adjustments.

Recovering food to feed people & livestock, and composting is just the tip of an iceberg, when compared to the total amount of food waste. The remaining part, more than 95% of the total food waste, is processed based on two general approaches. The first comprises getting rid of the waste and the second option is possibly deriving some benefits such as energy generation from the waste. The methods in these options comprise landfilling & incineration with and without energy recovery.

3.1. Landfilling

Landfill is a term describing the disposal of waste materials by burial and is in fact the oldest means of waste treatment. Each tonne of landfilled food waste generates, at atmospheric pressure, approximately 125 m³ of landfill gas [33]. Landfill gas contains 60 to 65% methane and 35 to 40% carbon dioxide. Methane, CH₄, is the simplest alkane and has 21 times more global warming potential compared to carbon dioxide over a time span of 100 years [34]. Landfills are responsible for approximately 8% of world's anthropogenic methane emissions [35]. In countries with high gross domestic product, GDP, this value goes up to 30 to 37%.

There are many other problems related to landfills such as leaking of leachate into soil and groundwater. Leachate is a potentially toxic liquid that drains from the landfill. Landfills produce between 0.17 and 0.25 m³ of leachate per ton of municipal solid waste [36]. Due to these problems, new methodologies and techniques are being developed for the utilisation of landfill gas and decreasing leachate production from landfills.

In the United Kingdom, 28 million tonnes of municipal waste is produced annually, of which 83% ends up in landfill sites [12]. Around 60% of the municipal waste is biodegradable. Biodegradable waste is mostly food waste. The impact of food waste on the environment is massive. When a food is wasted all the carbon generated as it was produced, processed, transported, and stored are also wasted. It is estimated that 20% of the United Kingdom's greenhouse emissions is related to this problem and this is equivalent to at least 15 million tonnes of carbon dioxide every year [12, 37].

3.2. Incineration

Apart from landfilling, municipal solid wastes, MSW, are generally treated by combustion or incineration. The major advantage of incineration is the reduction in the volume of the MSW. Moreover, when properly equipped, an incinerator can be used as a waste-to-energy facility to generate electricity. Heat released from the combustion of MSW can be used to produce steam, which can turn a steam turbine to generate electricity. Because no new fuel sources are used other than the waste, MSW is often considered as a renewable power source. In the United States, there are 89 operational MSW-fired power generation plants, generating approximately 2,500 megawatts, or about 0.3 percent of total national power generation [38].

Incinerators must be operated simultaneously with landfill systems in order to dispose the ashes. Burning waste at extremely high temperatures destroys chemical compounds and disease causing bacteria. Therefore, incinerated MSW does not cause further environmental problems at the landfill sites. However, incineration of food waste as a part of MSW alone causes serious environmental problems. Burning MSW produces carbon dioxide, nitrogen oxides and sulphur dioxide as well as trace amounts of toxic pollutants, such as mercury compounds and dioxins. Assuming, organic wastes from households is entirely made up from food wastes higher heating value for food wastes was taken as 6.4 MJ/kg [40].

4. Development of the food waste problem in the future

Adhikari and colleagues explained the future trends in global food waste problem in the following paragraph as [33]: On a global scale, municipal solid waste and urban food waste production are predicted to increase by 51 and 44%, respectively, from 2005 to 2025. In Asia, urban food waste production is likely to experience the largest increase in the world due to the rapid economic and industrial development in these countries. The urban food waste in Asiatic countries could rise from 278 to 416 million tonnes per year during the period.

If present municipal solid waste management policies are maintained, landfilled urban food waste is predicted to increase the annual world methane emissions from 34 to 48 million tonnes in the same period. Consequently, the landfill share of global anthropogenic methane emissions will increase from 8% to 10% [35].

The current practice of urban food waste management has some fundamental flaws. Therefore, it should be changed

in order to decrease the environmental impact. It is suggested that a fourth R, "Reprocess", could be added to the classical 3Rs of reduce, reuse, and recycle of the waste management strategies. Reprocessing in this context means, conceptualisation and development of completely new processes that utilise the waste as a raw material.

In this regard, new food waste valorisation practices aiming to achieve sustainable development and a globular economy should focus on innovative low environmental impact legislation compliant technologies able to convert this waste into value-added products [39].

5. Computed energy content of food wastes

When food wastes are dumped at landfills, all the energy stored in them is lost. However, there is no data in the literature about the amount of energy dissipated to the nature via this route. In order to calculate the energy content of the food waste first energy densities must be calculated. Food waste contains anything from vegetable peels to fishes. Therefore, it is easier to calculate an average energy density, higher heating values, for food waste. Assuming, organic wastes from households is entirely made up from food wastes higher heating value for food wastes was taken as 6.4 MJ/kg [40]. Meraz and colleagues used different computational models based on elemental composition of food wastes and experimental data for calculating the higher heating values of food wastes [41]. Using the computational data and 4 different equations from Meraz and colleagues work, a global average HHV value of food waste in MSW produced were estimated as 6.124 MJ/kg. In this study, the global HHV value for food wastes is taken as average of the values reported as 6.262 MJ/kg [40, 41]. Using the global annual food waste data in Table 1, the energy content of food wastes for different countries were estimated and reported in Table 2.

Table 2. Computed Annual Average Energy Content of Food Wastes from Different Countries in 2010

Country	Computed Average Energy Content, PJ
United States	494.7
Japan	119.0
Taiwan	103.3
United Kingdom	68.9
Korea	26.9
Singapore	3.6

According to the Energy Information Administration, EIA, of the US government, delivered annual energy consumption of the US food industry is 1160 PJ [42]. Therefore, energy worth 42.6% of delivered energy to the US food industry is lost at the landfill sites with the current food waste rate. Correspondingly, for Japan, hydroelectric production is 323.2 PJ [43]. Therefore, energy worth 36.8% of the hydroelectric power generation of Japan is wasted when food wastes are dumped at landfill sites. According to the Department of Energy and Climate Change, DECC, of the UK government, the current industrial energy demand provided by renewable resources in the UK is equal to 62.8 PJ. Therefore, energy worth more than 100% of current renewable energy demand of UK industries is wasted at landfill sites. This is shocking. Consequently, dumping food wastes into landfills does not only cause environmental problems but also a valuable bioenergy source is lost.

6. Conclusions

Food waste is a big problem for the developed economies of the world. In this study the size of the global food waste problem is pinpointed in detail. When food wastes are dumped at landfill sites together with the environmental problems caused by anaerobic digested the energy stored in the food wastes are also lost. However, if food wastes were processed via landfill bioreactors for landfill gas production or incinerated the energy content of these wastes can be harnessed and the environmental problems caused at the landfill sites can be tackled in a sustainable manner. Conclusively, in this study, the energy content of the food wasted in major economies of the world was calculated using models and data extracted from the literature. The results clearly pinpointed the huge amount of energy lost at the landfill sites, which could have been utilised either for power production or converted into value-added products using novel biorefinery technologies.

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